

Bose-Einstein Correlations
in
Deep Inelastic e^+p Scattering
at HERA

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for the
H1 collaboration

Overview

1. Introduction
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2. Introduction

1.1. Bose-Einstein Correlations are consequence of fundamental physics principle

the wave function of identical bosons is symmetric under particle exchange

→ quantum mechanical interference

→ identical bosons prefer to occupy same quantum state

→ they tend to group in phase space

manifestation of Bose-Einstein statistics

→ observed correlations called
Bose-Einstein Correlations (BEC)

1.2. History

1953

first use of intensity interferometry

Radio-astronomy:

Hanbury-Brown and Twiss

detect simultaneously & in different detectors photons emitted from different parts of stellar object

determine product of intensities as function of distance between detectors

correlation distance between detectors is measure of angular diameter of stellar object

1959

Particle Physics:

G. & S. Goldhaber, Lee and Pais

tendency of like-sign π pairs to have smaller opening angles than unlike-sign π pairs

correlation in momentum space is a measure of the effective size of pion source in real space

Since 1959:

BEC studies

- in different interactions
- in a wide range of CMS energies
- using variety of parameterizations

→ information about boson-emitting source

1.3. Parameterizations and Interpretations

two-particle correlation function

$$R(p_1, p_2) = \frac{\rho_2(p_1, p_2)}{\rho(p_1)\rho(p_2)}$$

p_i 4-momentum of particle i

$\rho_2(p_1, p_2)$ two-particle density distribution

$\rho(p_i)$ single-particle density distributions

Traditional view (geometrical interpretation):

$$R(p_1, p_2) = 1 + \lambda |\tilde{\rho}(T)|^2$$

$\tilde{\rho}(T)$ normalized Fourier transform
of source intensity
source consisting of independent radiators

$$T^2 = -(p_1 - p_2)^2$$

λ incoherence

$\lambda = 1$ for a fully incoherent source

reduction of λ due to

- coherent production of pions originating from resonance decay
- detector deficiencies
- final state interactions
(Coulomb & strong $\pi\text{-}\pi$ interactions)

Goldhaber / Gaussian parameterization

Pion source

= sphere of emitters with Gaussian density

$$R(T) = R_0 \left(1 + \lambda \exp(-r^2 T^2) \right)$$

R_0 general normalization factor

r radius of sphere

$r^2 T^2$ can be decomposed into x , y , z components

determination of parameters requires high statistics

usually done for heavy ion BEC studies

Modern views:

Traditional interpretation assumes no
 (x, p) -correlations
(x 4-vector in real space)

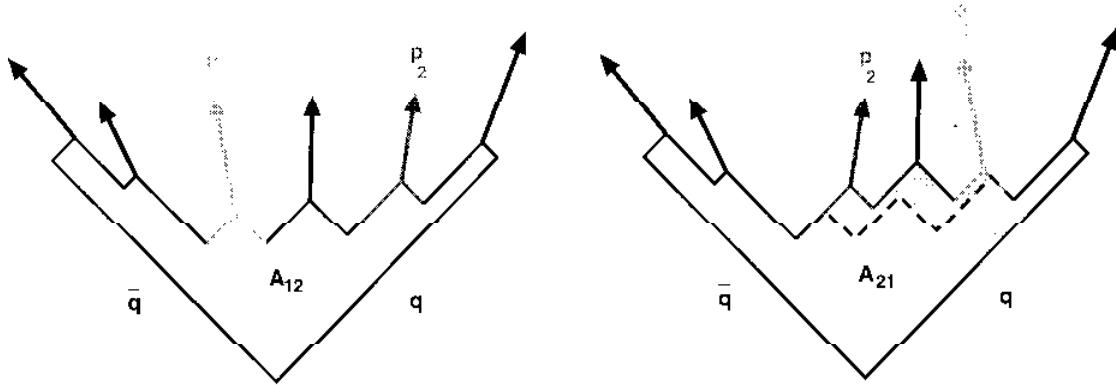
In HEP
emitters move relativistically wrt each other
→ (x, p) -correlations

→ r is measure of separation between
production points for which the momentum
distributions still overlap

r is independent of the total interaction
energy

In color-string fragmentation interpretation
 r is a measure of the string tension κ
 (Andersson, Hofmann and Bowler)
 (Particle World 2(1991)1, Phys. Lett. B169(1986)364)

e.g. two identical pions



yielding same final state
 different area, different phase

$$\psi \propto e^{i\kappa A_{12}} e^{-\frac{\mathcal{P}}{2}A_{12}} + e^{i\kappa A_{21}} e^{-\frac{\mathcal{P}}{2}A_{21}}$$

κ string tension
 \mathcal{P} splitting probability

Full calculations
 $\rightarrow R(T)$ roughly exponential

$$R(T) = R_0(1 + \lambda \exp(-rT))$$

$r(\kappa)$ is independent of the total interaction energy

Link with “intermittency” studies

intermittency =

large fluctuations in particle density

seen as increase of multiparticle correlation functions with decreasing phase-space bins.

increase stronger for like-charge samples
than for all-charge sample
→ BEC influence

increase is power-law like

Białas: if size of particle source fluctuates on event-by-event basis and/or
if source is self-similar (fractal-like) object

power law in invariant mass M of the pair

$$R(M) = A + B \left(\frac{1}{M^2} \right)^\beta$$

this parameterization has no scale variable

(Nucl. Phys. A545(1992)285c, Phys. Rep. 270(1996)1)

2. Experimental Information

2.1. Data sample

data taken with H1 detector at HERA
storage ring in 1994

$$27.5 \text{ GeV } e^+ \longleftrightarrow 820 \text{ GeV } p$$
$$\sqrt{s} = 300 \text{ GeV}$$

DIS events with $6 \leq Q^2 \leq 100 \text{ GeV}^2$
 $10^{-4} \leq x \leq 10^{-2}$

$$\rightarrow \begin{cases} 2500 & \text{diffractive events} \\ 48000 & \text{non-diffractive events} \end{cases}$$

integrated luminosity 1.26 pb^{-1}

diffractive events selected by requiring large
pseudo-rapidity gap around proton remnant
direction

all charged particles are assumed to be pions

2.2. Extracting BEC

$$R = \frac{\rho_2^l(T)}{\rho_2^{ref}(T)}$$

$\rho_2^l(T)$ two-particle distribution for like-sign particles

$\rho_2^{ref}(T)$ reference distribution, containing same correlations as $\rho_2^l(T)$ except for BEC

T four-momentum difference of two particles

possible reference distributions:

event-mixed $\rho_2^m(T)$:
combining tracks from different events

unlike-sign $\rho_2^u(T)$:
combining tracks of opposite charge

Monte Carlo studies →

$\rho_2^m(T)$ is biased by topological, momentum
and charge conservation constraints

$\rho_2^u(T)$ is contaminated with dynamical corre-
lations of K_S^0 and resonance decays

Use MC without BEC to correct for short-
comings of reference distributions:

$$RR(T) = \frac{R^{data}(T)}{R^{MC}(T)}$$

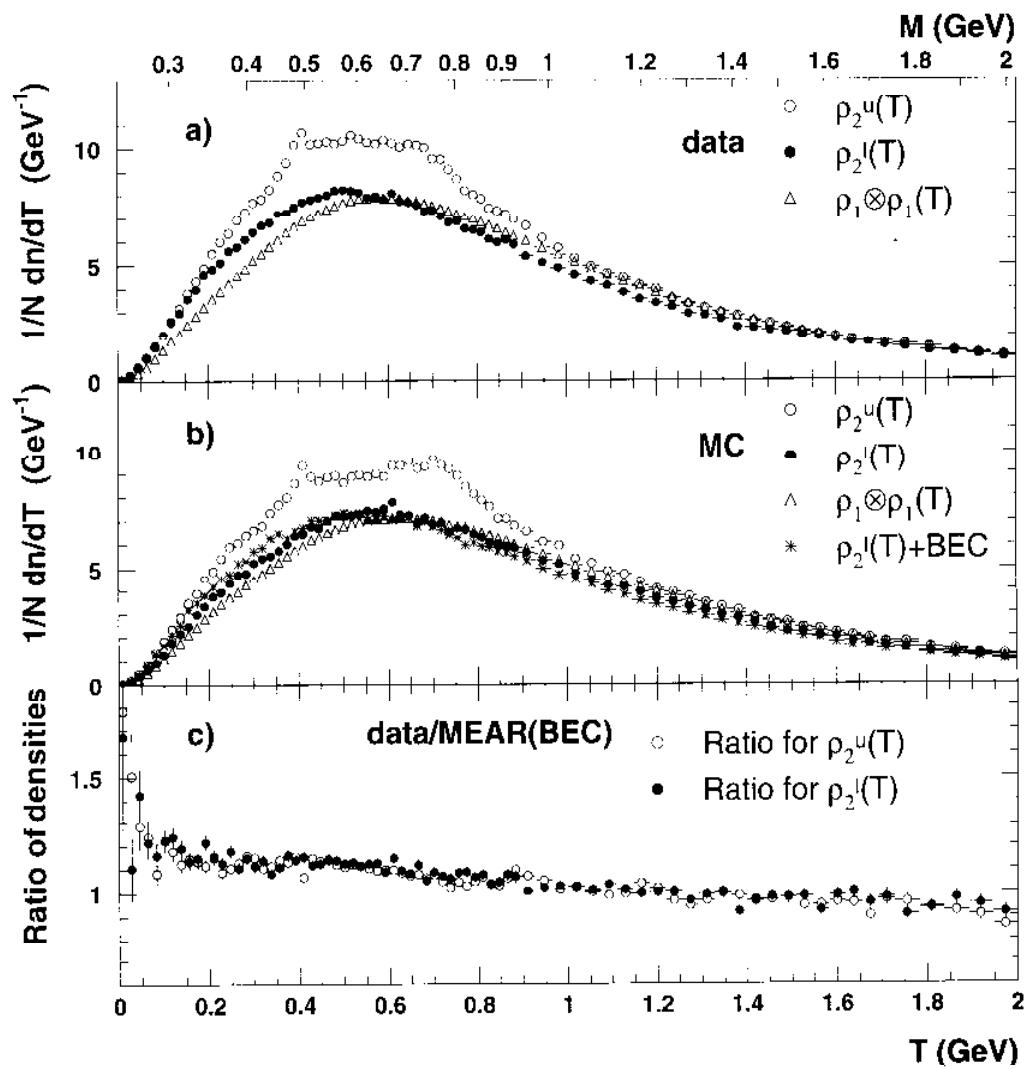
(this also corrects for detector acceptance
and kinematic cuts)

MEAR Monte Carlo is used

(MEAR = LEPTO6.1 + CDM as in ARIADNE4.03)

Only $\rho_2^m(T)$ will be shown

(smaller systematic errors, no resonance decays)



2.3. Parameterizations

Gaussian

$$RR(T) = R_0 (1 + aT) \left(1 + \lambda \exp(-r^2 T^2) \right)$$

Exponential

$$RR(T) = R_0 (1 + aT) (1 + \lambda \exp(-rT))$$

R_0 : global normalization factor

a : allows for long-range correlations

λ : incoherence parameter

r : length-scale variable

Power Law

$$RR(M) = A + B \left(\frac{1}{M^2} \right)^\beta$$

M : invariant mass of the pair

3. Diffractive

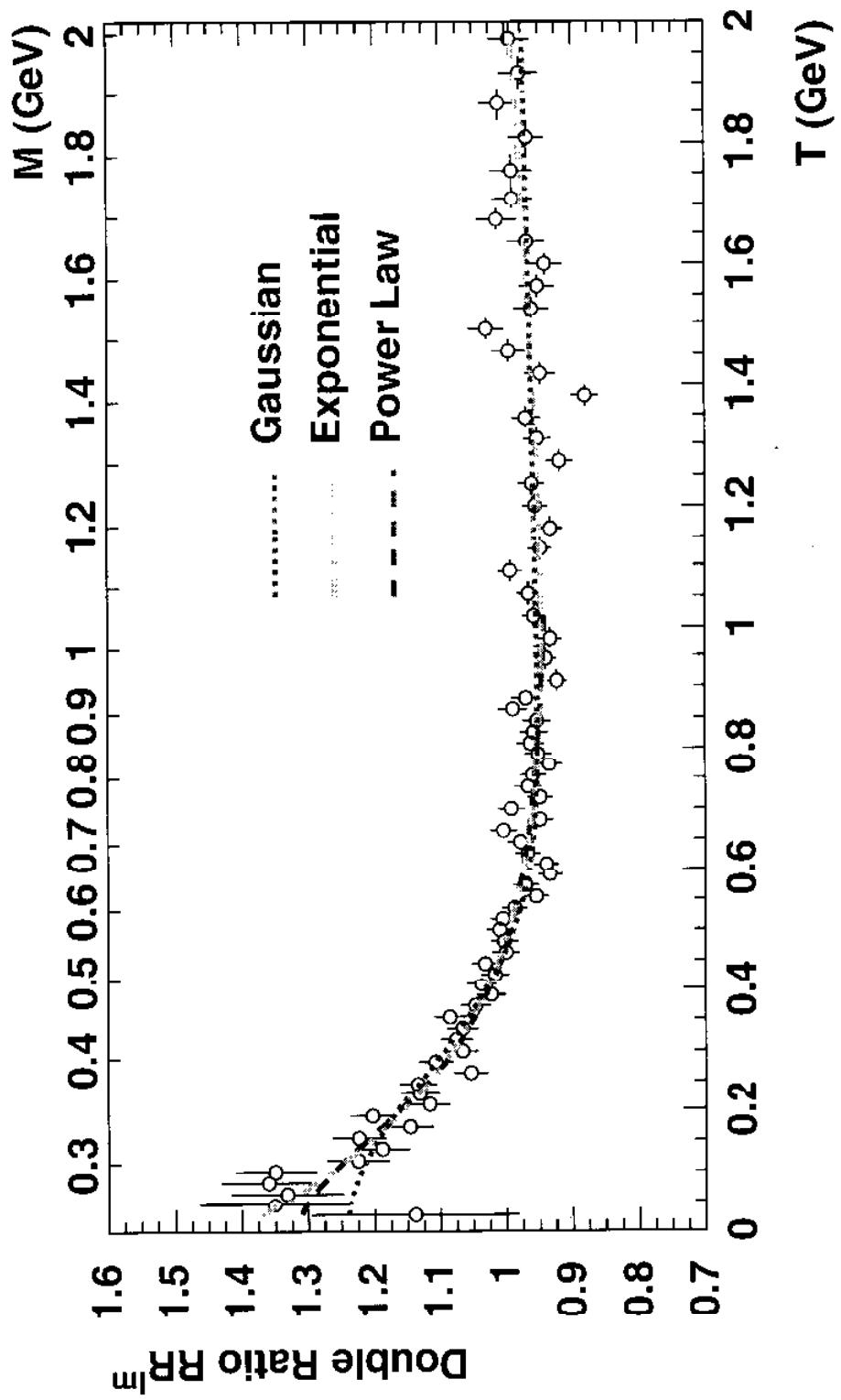
3.1. Fit results for non-diffractive events

	Gaussian	Exponential
$a[\text{GeV}^{-1}]$	0.02 ± 0.01	0.08 ± 0.04
$r[\text{fm}]$	0.54 ± 0.03	0.68 ± 0.11
λ	0.32 ± 0.02	0.64 ± 0.06
χ^2/ndf	96/72	85/72

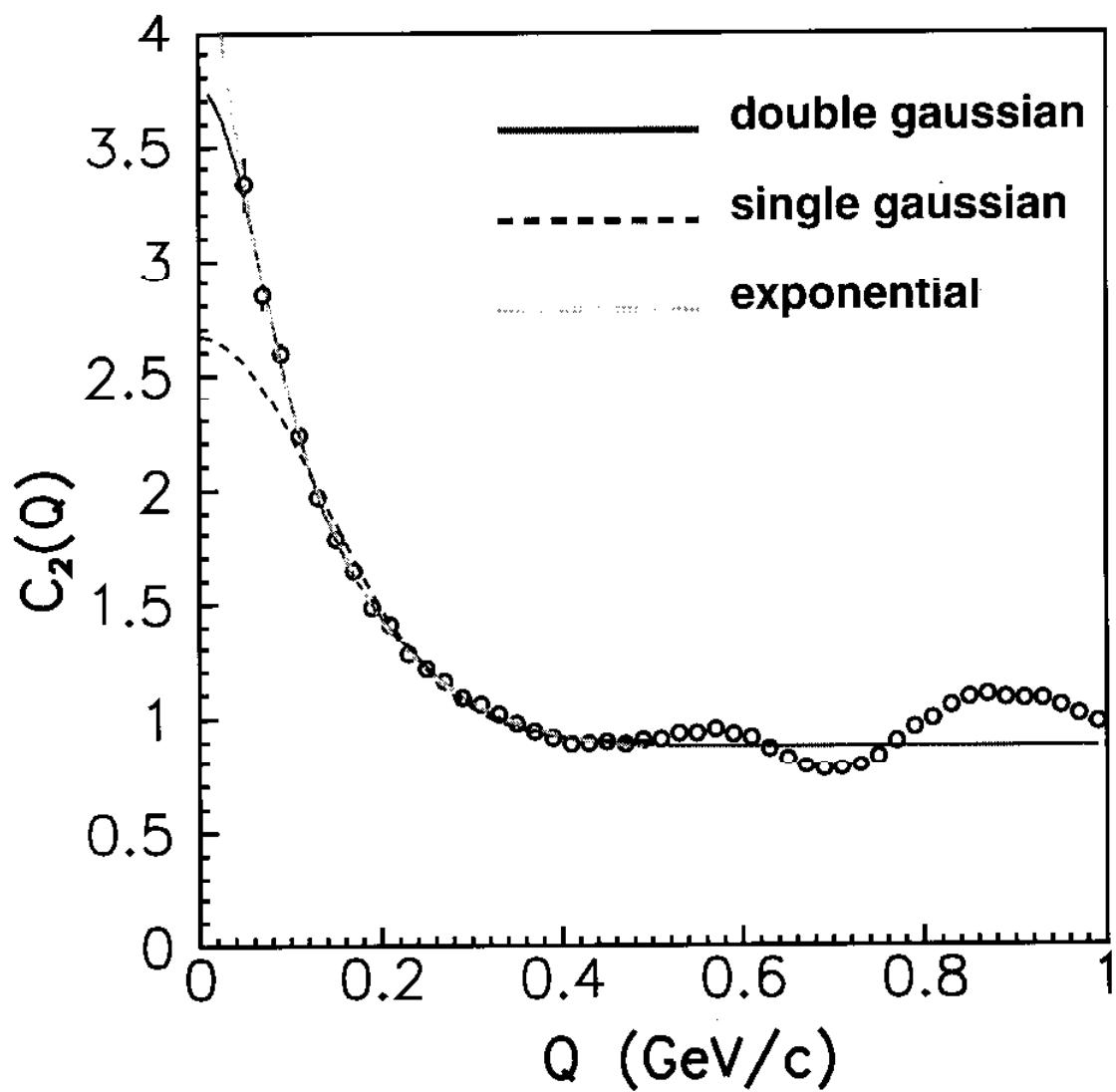
	Power law
β	1.20 ± 0.15
$B[\text{GeV}^{-2\beta}]$	0.018 ± 0.006
A	0.93 ± 0.01
χ^2/ndf	49/49

BE correlation function decreases faster with T than a Gaussian

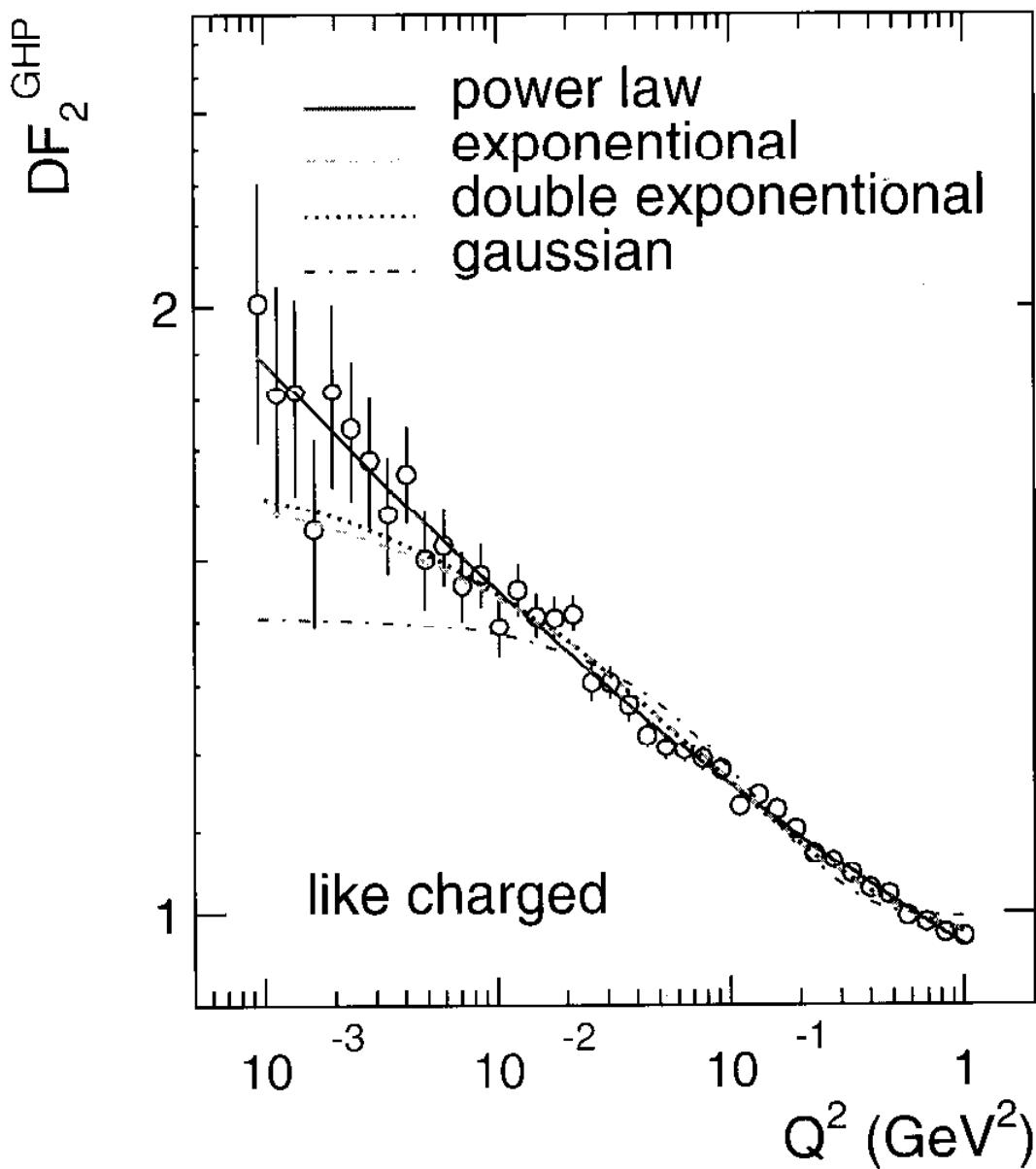
power law is valid alternative



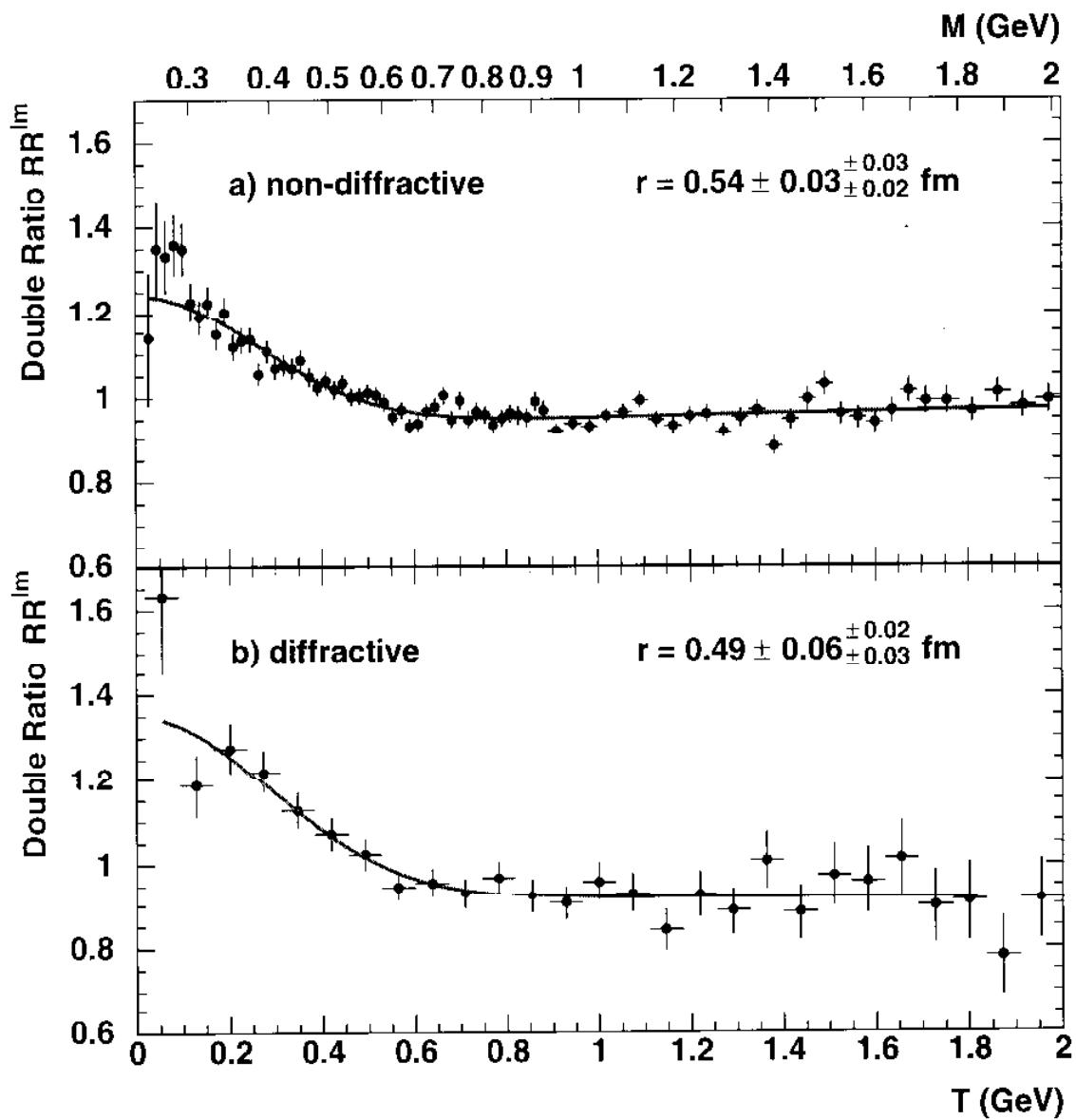
CLEAR ($\bar{p}p$ annihilations at rest)



NA22
($K^+/\pi^+ p$ at 250 GeV/c ($\sqrt{s} = 22$ GeV))



3.2. Diffractive vs. non-diffractive (Gaussian fits)



no statistically significant difference

3.3. Dependence on kinematic variables (Gaussian fits)

No x_{bj} dependence

No Q^2 dependence

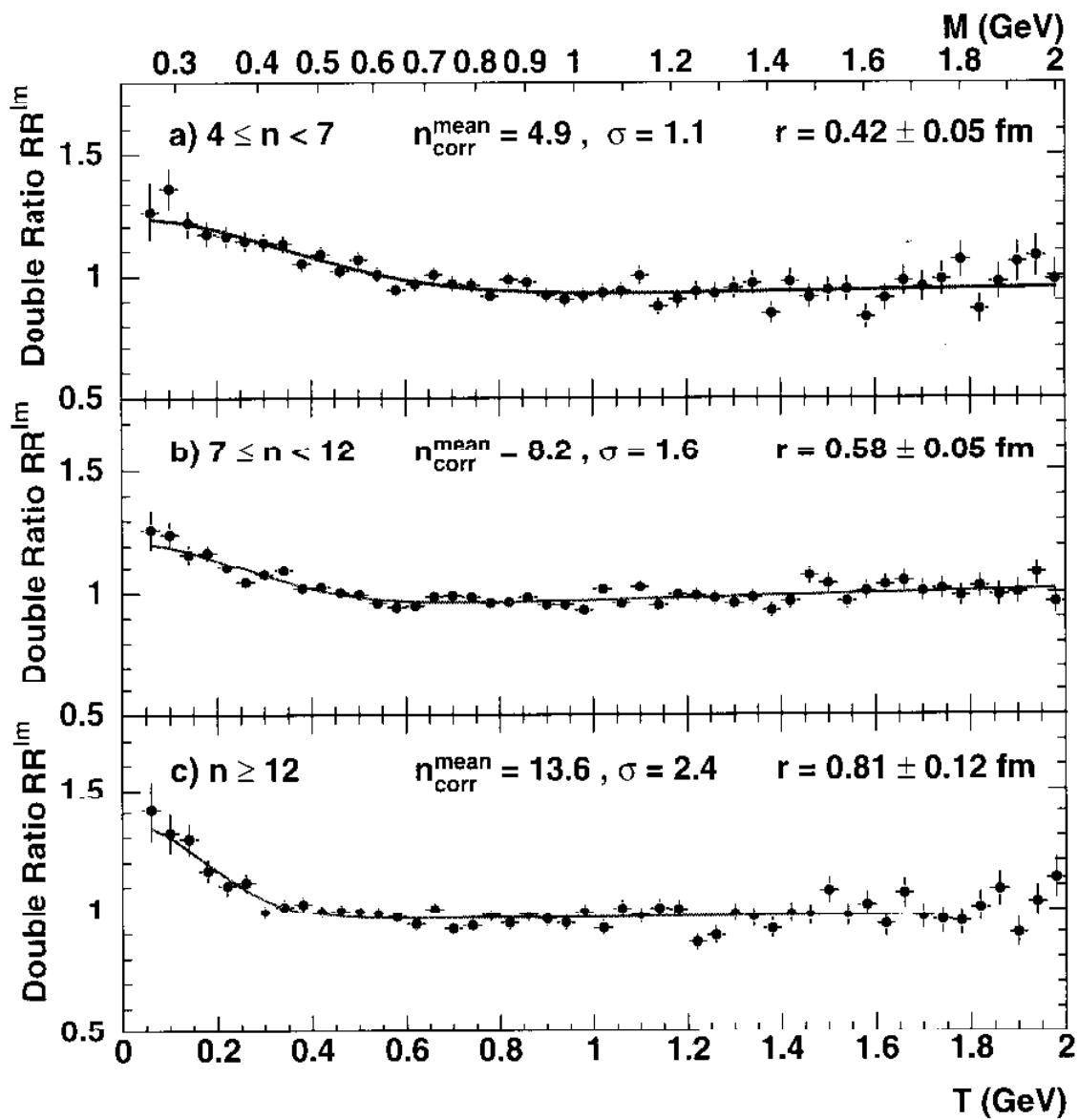
No W dependence

r tends to increase with multiplicity
but the statistical and systematical errors are
large

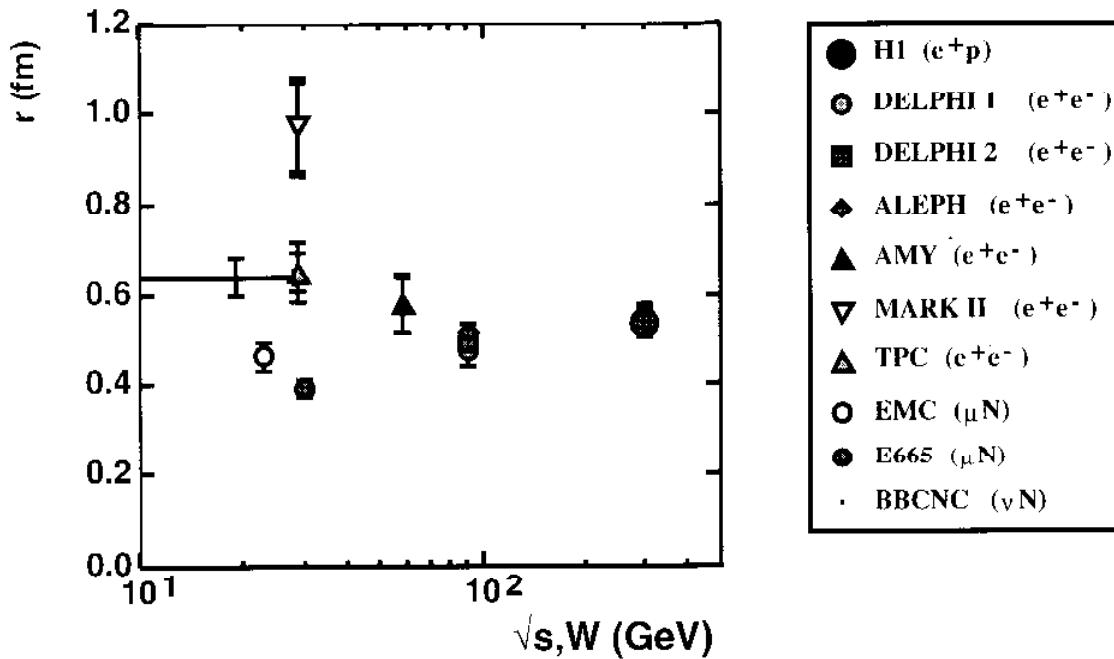
$$\frac{1}{\langle r \rangle} \frac{dr}{dn} = 0.085 \pm 0.026 \begin{array}{l} +0.057 \\ -0.048 \end{array}$$

Gaussian parameterization

r (fm)	0.60 ± 0.06	0.56 ± 0.05	0.44 ± 0.06
x	$0.0001 - 0.0006$	$0.0006 - 0.0019$	$0.0019 - 0.01$
r (fm)	0.52 ± 0.04	0.63 ± 0.08	0.47 ± 0.04
Q^2 (GeV 2)	$6 - 12$	$12 - 25$	$25 - 100$
r (fm)	0.52 ± 0.07	0.48 ± 0.03	0.68 ± 0.08
W (GeV)	$65 - 120$	$120 - 180$	$180 - 240$



3.4. Comparison with other experiments (Gaussian fits)



All values about the same
Except for MARK II

No evidence for energy dependence
No evidence for primary interaction
dependence

supports more recent interpretations of r

4. Summary

exponential and power-law parameterizations are valid alternatives for traditional gaussian parameterization

BEC increase faster with decreasing T than a gaussian

diffractive and non-diffractive samples yield same BEC

BEC seems independent of x_{bj} , W , Q^2

r (Gaussian fit) tends to increase with multiplicity

r (Gaussian fit) is independent of CMS energy and type primary interaction

the length-scale variable r is related to a local size rather than to the total size of the source (string-model, Andersson et al.)